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DRY GAS OPERATION OF BALL BEARINGS AT CRYOGENIC TEMPERATURES *

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Introduction

Previous work at the National Bureau of Standards Cryogenic Engineering Laboratory [1, 2] has shown the excellent endurance characteristics of some ball-bearing configurations while running submerged in liquid nitrogen.

A recent requirement for high-speed rotating machinery operating in a cold gaseous hydrogen environment has developed in Project Centaur. The application is for a phase-separation device to enable the venting of gaseous rather than liquid hydrogen from tankage in the absence of a gravitational field. The operating requirements on the bearings were indicated as follows: speed—9200 rpm; thrust load—30 lb; torque—as low as possible, but not to exceed 5 in.-oz per bearing; life—20 hr minimum. In the present work, tests have been conducted to determine if these requirements can be satisfied with ball bearings, and to extend the previous data to include dry hydrogen gas operation.

Apparatus

A photograph of the test apparatus is shown in Fig. 1. The equipment is shown in position for a bearing test at 20°K. From right to left, the main components

Fig. 1. Test apparatus.

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are a liquid-hydrogen supply dewar, a liquid-nitrogen precooling heat exchanger, the ball-bearing test apparatus, and the instrumentation console.

The bearing test apparatus is shown in Fig. 2. In the initial tests, a bellows arrangement, located between the two test bearings, was used to apply a thrust load to both bearings. In later tests, a spring replacement was used to eliminate

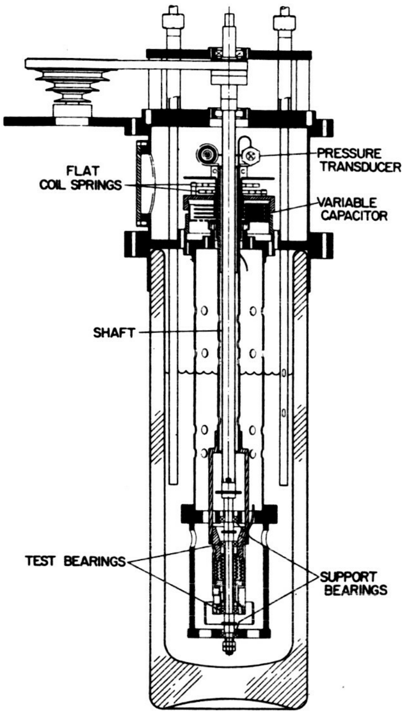

Fig. 2. Bearing test machine.

load variation with small temperature fluctuations. Torque, per pair of test bearings, was monitored by means of a spiral spring and capacitance technique. Tests were made at a constant speed of 9200 rpm. The apparatus as shown was primarily used for submerged liquid tests [1]. A major modification for gas tests was to provide gas disturbance nozzle rings adjacent to the bearings in place of turbines for liquid circulation. These are shown in the exploded view (Fig. 3). The outside bearings support shaft weight and induce radial load. The mechanism

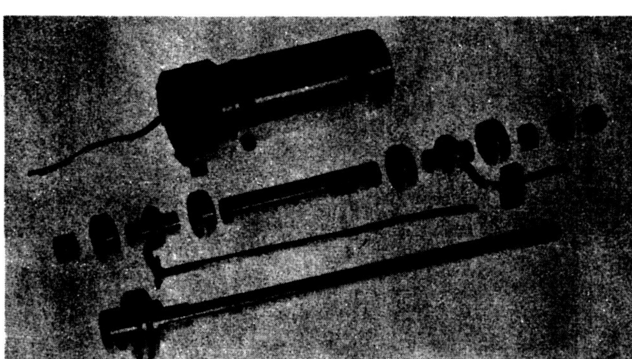

Fig. 3. Bearing test assembly.

shown at top center applies the thrust load to the two center test bearings.

Hydrogen gas for cooling the bearing is brought into the tester through an arrangement of heat exchangers and mixing valves used to vary the inlet temperature and flow rate of the gas as required. Coolant gas is piped to the two nozzle rings and discharged through 6 holes, 0.040 in. in diameter, facing each test bearing, and 4 holes of the same diameter facing each support bearing. The gas passes through the holes at low velocity, usually with a pressure drop of 1 to 2 psi. In the present tests, the quantity of gas discharging from the 6 holes at each test bearing was assumed to be active in the cooling process. Assuming equal volumetric flow per hole, each test bearing received 30% of the total flow.

Thermocouples were used to measure the temperature of the inlet gas stream. Rough temperature measurements of the support-bearing outer ring were also obtained.

Bearings

The bearings tested were ball bearings of 26-mm OD by 10-mm bore having 440-C stainless steel balls and races. The separator material was Rulon A (reinforced polytetrafluoroethylene resin which contains an inert, inorganic, silicate base filler). Selection was made on the basis of the most successful material determined, thus far, from tests of bearings submerged in liquid nitrogen [1, 2]. Two tests (four bearings) were also performed using carbon—graphite compounds. The latter separators disintegrated in a short time; however, it is difficult to draw conclusions based on these meager experimental data.

Results

The bearings with Rulon A separators have performed with good success. To date, a total of nearly 250 hours have been accumulated using nine pairs of test bearings. No failures occurred when sufficient cooling gas was provided. The criterion for failure has been excessive increase in torque.

In the course of the tests it was observed that a definite minimum, or critical, flow rate of coolant gas was required to maintain a constant, minimum torque. When flow rates less than the critical were allowed, the torque increased rapidly. However, the initial torque was recovered if the flow rate was again increased within a reasonable length of time. The more lightly loaded bearings have recovered their original torque after developing a torque 20 times the minimum. The heavily loaded bearings did not always fully recover if the torque was allowed to increase more than a factor of two above the minimum.

Table I. Typical Gas Flow—Temperature Relationship

Average load, lb	Torque (two bearings), in.-oz	Critical flow (total), scfm	Average gas temperature, °C
35	3-5	2.0-2.5	-145
35	3-5	2.0-2.5	-105
35	3-5	3.0-4.0	-30
35	3-5	3.8-4.2	+40
115	10-14	2.0-3.0	-151
115	10-14	3.5-4.0	-107

Table I lists typical critical flow vs. temperature for two thrust loads. The flow value given was the total hydrogen coolant supplied to the tester. Critical flow increased at the higher gas temperatures. The bearing load did not greatly influence the critical flow, but load apparently determined the minimum torque. Torque did not vary significantly with inlet gas temperature.

Two additional tests were conducted to obtain endurance data under essentially steady conditions. Table II shows the results of these tests. Bearing wear was measured by the "stick-out" (position of inner ring relative to outer ring, under load) method. The wear in each case was within the accuracy of measurement (0.0001 in.). Starting torque was also measured at various intervals during the test. The apparatus was stopped and turned both manually and by the drive motor. The starting torque by both methods was constant and approximately 2 to 3 times the running torque throughout the test.

Table II. Endurance Tests at 9200 rpm

Run	Average load, lb	Torque (two bearings), in.-oz	Total average flow, scfm	Gas temperature, °C	Total operation, hr
I	45	2	4.0	-180	55
II	35	1	3.5	-251	21

In all tests, the initial running torque for new bearings, or used bearings which had been dismantled, was somewhat higher than the values given. A steady, low torque was usually obtained after 1 to 2 hours of running.

Summary

If proper cooling is maintained, this bearing should easily satisfy the requirements previously outlined for a phase-separation device. The minimum cooling gas (Run II, Table II) requirement was found to be 0.5 to 1 scfm per bearing, resulting in a torque of less than 1 in.-oz at 9200 rpm and approximately 20°K.

The results obtained are less extensive but similar to those obtained in the submerged liquid-nitrogen tests. These previous tests indicated that endurance exceeding the recommended minimum life of warm, lubricated bearings may be achieved. More extensive endurance testing may also confirm this for bearings operating in dry hydrogen gas.

The Centaur contractor, General Dynamics/Astronautics, has successfully designed and tested a phase-separation device using identical bearings. This device will be further subjected to endurance tests of 200 hours. An early test flight will also carry an identical unit.

References

1. J.A. Brennan, W.A. Wilson, R. Radebaugh, and B.W. Birmingham, Advances in Cryogenic Engineering, Vol. 7, K. D. Timmerhaus (ed.), Plenum Press, Inc., New York (1962), Paper G-2.
2. W.A. Wilson, K.B. Martin, J.A. Brennan, and B.W. Birmingham, ASLE Trans., Vol. 4, 50 (1961); also in Advances in Cryogenic Engineering, Vol. 6, K.D. Timmerhaus (ed.), Plenum Press, Inc., New York (1961), p. 245.

Discussion

Question by R.N. Moore, Lockheed Aircraft - California Div.: What was the time cycle of the testing reported in this paper? Was it on a continuous operation basis once it was started or cycled on—off on a time basis?

Was the test bearing always started in the specific gas environment or was the gas environment introduced after bearing rotation was initiated in a liquid or another gas?

Answer by Author: The submerged liquid tests reported in Paper G-2 were continuous. The gas tests reported here required constant supervision and were therefore intermittent to agree with normal working hours. Some cyclic operation was manually introduced to check starting torque values. A programed on—off test has not been done.

A 5-min run was conducted in a moderate vacuum in the absence of gas flow without deleterious effects. Otherwise, the hydrogen gas flow was always established before starting the test; however, flow rates and temperatures were often changed while running.